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ADVANCED IMPROVED DIGITAL CONTROLLER FOR BLDC MOTOR TO REDUCE TORQUE RIPPLES

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ABSTRACT

Brushless DC (BLDC) motors are attaining higher priority in industrial automation, computers, aerospace, military, household appliance and traction applications because of its high efficiency, high power density and low maintenance cost. To control a BLDC machine, it is generally required to measure the speed and position of rotor by using the sensor. Using the measured value of rotor position, each inverter phase acting at precise time will be commutated. This paper presents a simple digital pulse width modulation (PWM) control technique for trapezoidal brushless DC (BLDC) motor drives. This digital PWM controller fed to BLDC motor is designed and implemented by mathematical analysis. The new controller is adopted to reduce the torque ripple. This scheme reduces the cost and complexity of motor control the performance of the BLDC motor drive verified via simulations.

KEYWORDS: Brushless DC Motor (BLDCM), Voltage Source Converter (VSC), Digital Pulse Width Modulation (DPWM), Speed Controller, Current Controller

INTRODUCTION

Now-a-Days, Brushless DC (BLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance and are widely used in many motor applications developing high torque with good speed response. The BLDCM has a higher efficiency than an induction machine. This is primarily because there are negligible rotor losses in permanent magnet machines; the rotor losses in the IM, however, can be considerable, depending on the operating slip. This discussion is applicable to constant flux operation.

Proportional-integral (PI) control with hysteresis or pulse width modulation (PWM) switching is the most widely used speed control technique for BLDC motors with trapezoidal back EMF. It can be easily implemented on analog or digital components because it is well understood, simple, and in practice for a fairly long period of time. To enhance the performance or to reduce the cost has been focus of development work for a long time. Cost and implementation complexity are often the most important factors for design trade-offs between techniques, implementation, and strategy of motor control hardware.

This paper proposes a digital control for BLDC motor drives, which is low cost and simple to implement. This digital PWM controller treats the BLDC motor as a digital system. The BLDC system is only allowed to operate at a

low duty (DL) or a high duty (DH). Speed regulation is achieved by alternating between low duty and high duty ratios. This new concept helps to reduce the cost and complexity of motor control hardware and in turn can boost the acceptance level of BLDC motors for commercial mass production applications and successfully fulfill the promises of energy savings associated with adjustable speed drives [7]. For the controller presented in this paper, characteristic equation of a BLDC machine, which involves simple first-order non- homogenous differential equations, was used to design the controller.

BLDC MOTOR DRIVE SYSTEM

The permanent magnet synchronous motor (PMSM) and the Brushless DC motor (BDCM) have many similarities. They both have a permanent magnet (PM) on the rotor and require alternating stator currents to produce constant torque. The difference in these two machines is that the PMSM and the BDCM have sinusoidal and trapezoidal back emfs, respectively. This means these two machines have different operating characteristics and requirements. Although some of the fundamental differences between these two machines are known. The reasons for choosing brushless motor over the brush type DC motor are well known and include robustness, higher torque and speed bandwidths, and lower maintenance.

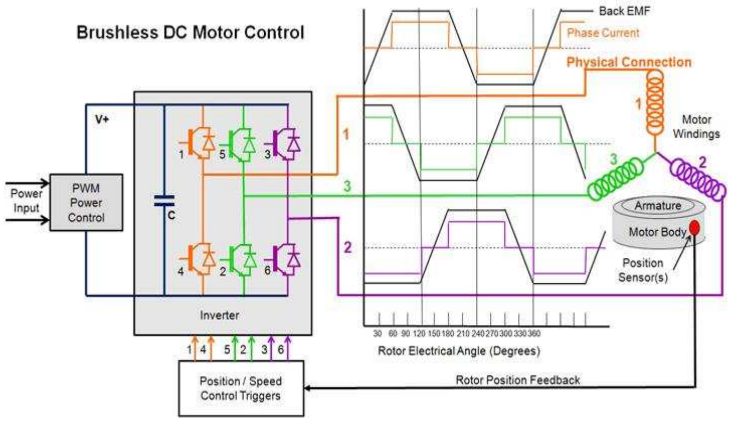

Figure 1: BLDC Motor Drive and Control

The operation of BLDC motor with hall sensors can be explained as shown in figure, basically the purpose of the hall sensors is to give the information about the rotor position. Hall sensors are inserted in the stator core with 120 degree phase displacement in such a way that, the sensors that related to particular phase is 120 degree lagging behind in space. These hall sensors are able to generate the required logic signals for decoding the induced back emfs. The Hall sensor signals are like square wave with logic 1 for 180 degree & logic 0 for remaaining 180 degree. This hall sensor signals $H_{a,}$ H_b and H_c are 120 degree out of phase one another. This induced emf signal is divided into six intervals each of 60 degree. The three hall sensor signals (Boolean) are able to give 8 possible combinations but out of these all 1’s and all 0’s case is neglected so the remaining 6 states of hall signals will decode the induced emf. Now, the induced emf signals will generate the required gate signals of the inverter for proper commutation of the inverter.

CONTROLLING CIRCUIT

- **PI Controller**

The PI control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional and integral terms are summed to calculate the output of the PI controller. Defining u(t) as the controller output, the final form of the PI algorithm is:

$$u(t)=K_p\, e(t)+K_I \int_0^t e(t) \tag{3.18}$$

Where

Kp**:** Proportional gain, a tuning parameter

Ki **:** Integral gain, a tuning parameter

e(t): error = SP – PV

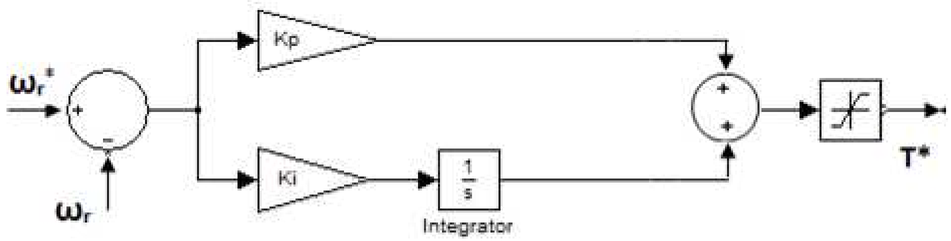

Figure 2: PI Controller

Table 1: PI Controller

Parameter	Rise Time	Overshoot	Settling Time	Steady State Error	Stability
KP	Decreases	Increases	Small Changes	Decreases	Degrades
KI	Decreases	Increases	Increases	Decreases significantly	Degrades

- **Speed Control**

Commutation ensures the proper rotor rotation of the BLDC motor, while the motor speed only depends on the amplitude of the applied voltage. The amplitude of the applied voltage is adjusted using the PWM technique. The required speed is controlled by a speed controller, which is implemented as a conventional Proportional-Integral (PI) controller. The difference between the actual and required speeds is input to the PI controller which then, based on this difference, controls the duty cycle of the PWM pulses which correspond to the voltage amplitude required to maintain the desired speed.

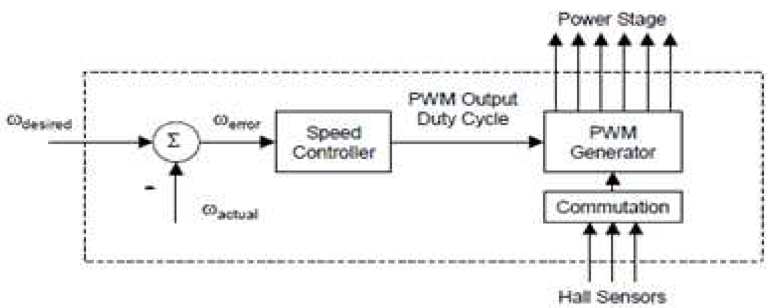

Figure 3: Speed Controller

- **Modeling of BLDC Motor**

The equivalent circuit of a Y-connection BLDC motor

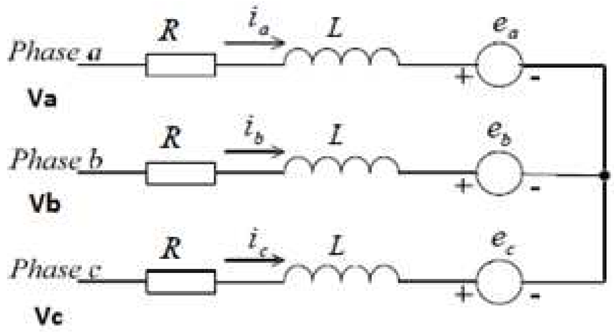

Figure 4: Equivalent Circuit

A BLDC motor has three stator windings and permanent magnets on the rotor. Its voltage equation of three windings with phase variables is:

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} Ea \\ Eb \\ Ec \end{bmatrix}$$

where Va, Vb, Vc are the phase voltages, ia, ib, ic are the phase currents, Ea, Eb, Ec are the phase back- EMF, R is the phase resistance, L is the self inductance of each phase.

Mechanical Equation

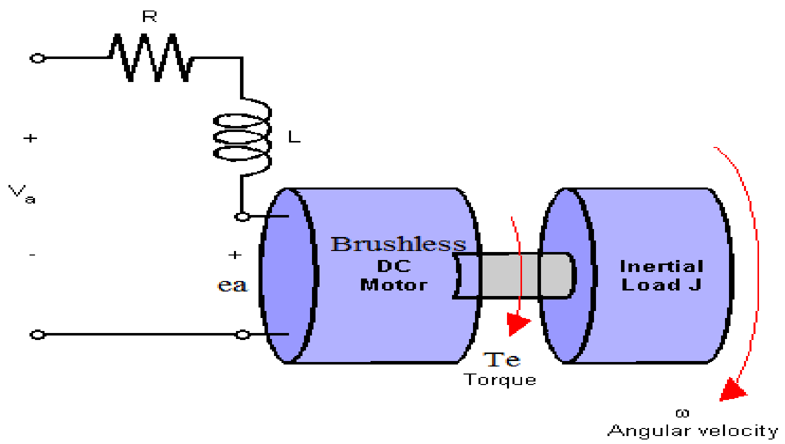

Figure 5: Mechanical Load

And the electromagnetic torque equation is

$$Te = \frac{1}{wm}(iaea + ibeb + icec)$$

where ωm is the speed of the rotor and Te is the electromagnetic torque.

The back EMF equation is

$$\begin{bmatrix} Ea \\ Eb \\ Ec \end{bmatrix} = \lambda m \ \omega m \begin{bmatrix} fa\,(\theta r) \\ fb\,(\theta r) \\ fc\,(\theta r) \end{bmatrix}$$

$$Fa\ (\theta a)=\begin{cases} \frac{6}{\pi}\theta;\ 0 \le \theta \le \frac{\pi}{6} \\ 1;\ \frac{\pi}{6} \le \theta \le \frac{5}{6}\pi \\ -\frac{6}{\pi}\theta;\ \frac{5}{6}\pi \le \theta \le \frac{7}{6}\pi \\ -1;\ \frac{7}{6}\pi \le \theta \le \frac{11}{6}\pi \\ \frac{6}{\pi}\theta;\ \frac{11}{6}\pi \le \theta \le 2\pi \end{cases} \tag{1}$$

$$Fb\ (\theta b)=\begin{cases} -1\ ;\ 0 \le \theta \le \frac{3}{6}\pi \\ \frac{6}{\pi}\theta - 4\ ;\ \frac{3}{6}\pi \le \theta \le \frac{5}{6}\pi \\ 1\ ;\ \frac{5}{6}\pi \le \theta \le \frac{9}{6}\pi \\ -\frac{6}{\pi}\theta + 10\ ;\ \frac{9}{6}\pi \le \theta \le \frac{11}{6}\pi \\ 1\ ;\ \frac{11}{6}\pi \le \theta \le 2\pi \end{cases} \tag{2}$$

$$Fc\ (\theta c)=\begin{cases} 1\ ;0 \le \theta \le \frac{\pi}{6} \\ -\frac{6}{\pi}\theta - 4\ ;\ \frac{\pi}{6} \le \theta \le \frac{3\pi}{6} \\ -1\ ;\ \frac{3\pi}{6} \le \theta \le \frac{7\pi}{6} \\ \frac{6}{\pi}\theta + 10\ ;\ \frac{7\pi}{6} \le \theta \le \frac{9\pi}{6} \\ 1;\ \frac{9\pi}{6} \le \theta \le 2\pi \end{cases} \tag{3}$$

where λm is the flux linkage, θr is the rotor position in radian and the functions Fa (θr), Fb (θr), Fc (θr) have the same shape as Ea, Eb, Ec with a maximum magnitude of ±1.The induced emfs do not have sharp corners because these are in trapezoidal nature.

SIMULATION RESULTS

Simulation studies of a BLDC Motor drive is undertaken using MATLAB/SIMULINK with a modeled BLDC Motor with specifications described in Table 1. The three phase inverter is also modeled and it is switched at a frequency of 10 KHz. The simulation block of BLDC Motor drive and the simulation diagrams respectively.

The rotor position is known from hall sensor signals and depending o it, the inverter switches are turned on and off so that a continues rotation is made possible. The switches are Turned ON with suitable PWM signals with required duty ratio is determined the digital controller.

Table 2: Data for BLDC Motor

Rated Voltage	160V
Rated Speed	1500rpm
Resistance	2.8ohm
Inductance	0.12mH
No. of Poles	4
Rotor Inertia	0.162Kg-cm^2

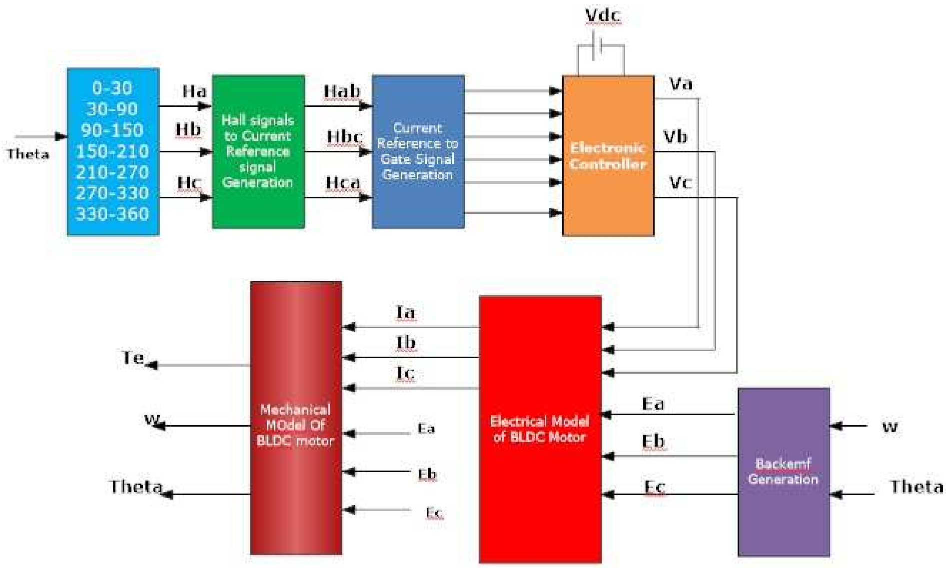

Figure 6: Block Diagram of Simulation of Proposed BLDC Motor

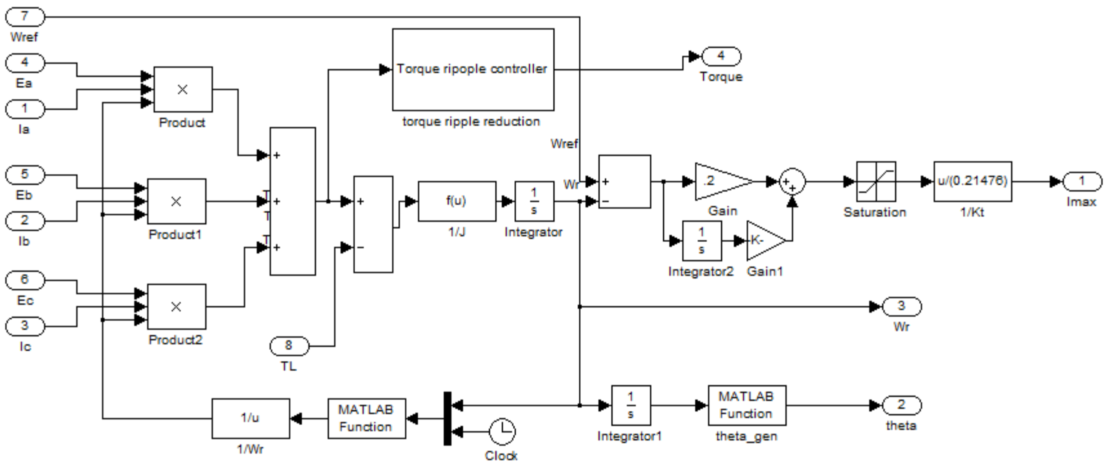

Figure 7: Simulation Control Block Diagram of BLDC Motor

The torque balance equation is expressed as

$$T_e = J\frac{d\omega_r}{dt} + B\omega_r + T_L$$

Where *J* is the moment of inertia of the rotor

B is the damping coefficient associated with the rotational system of the motor. It is often very small and neglected.

T_L is the mechanical load torque.

The rotor speed ω_r is expressed as

$$\omega_r = \frac{1}{J}\int\left(T_e - T_L\right)\cdot dt$$

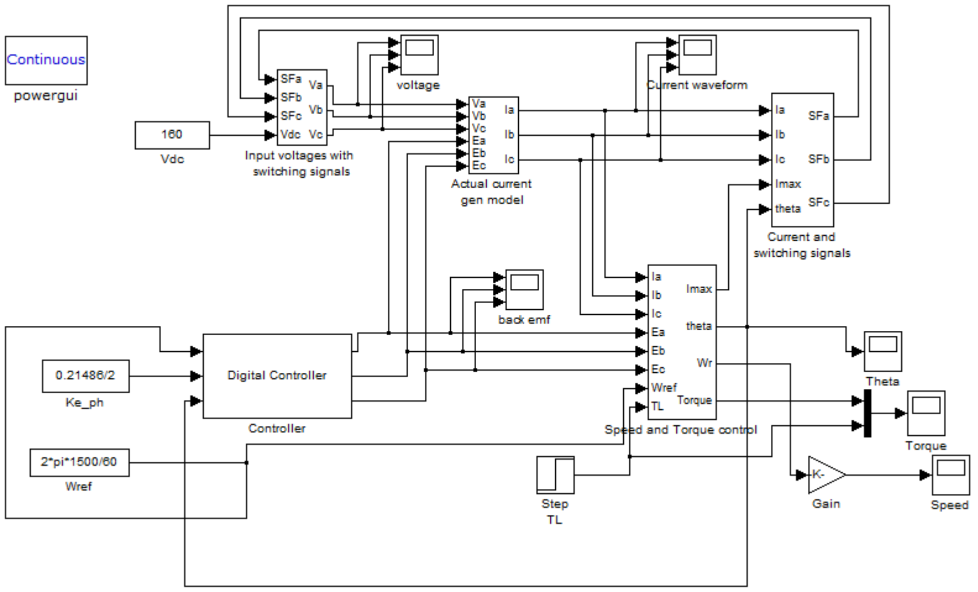

Figure 8: Simulation Diagram of Proposed BLDC Motor

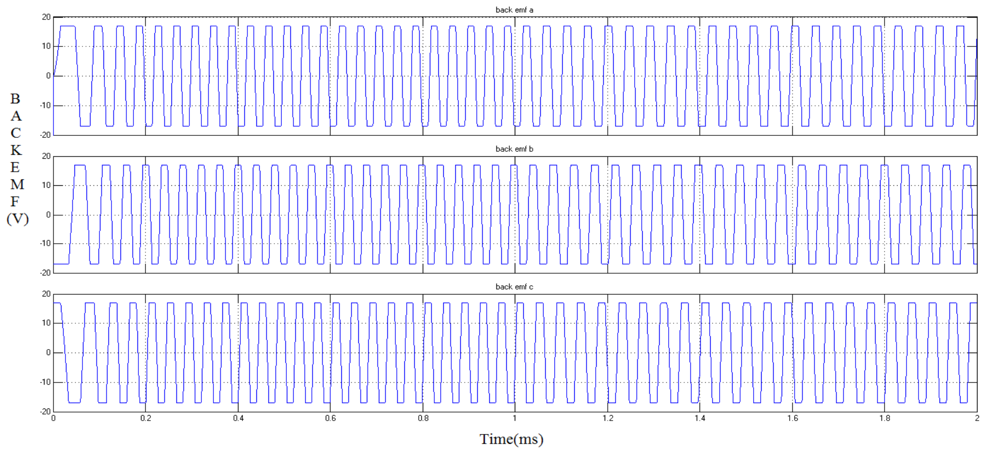

Figure 9: Simulated Waveforms of Back EMF at Reference Speed 1500rpm of with Load

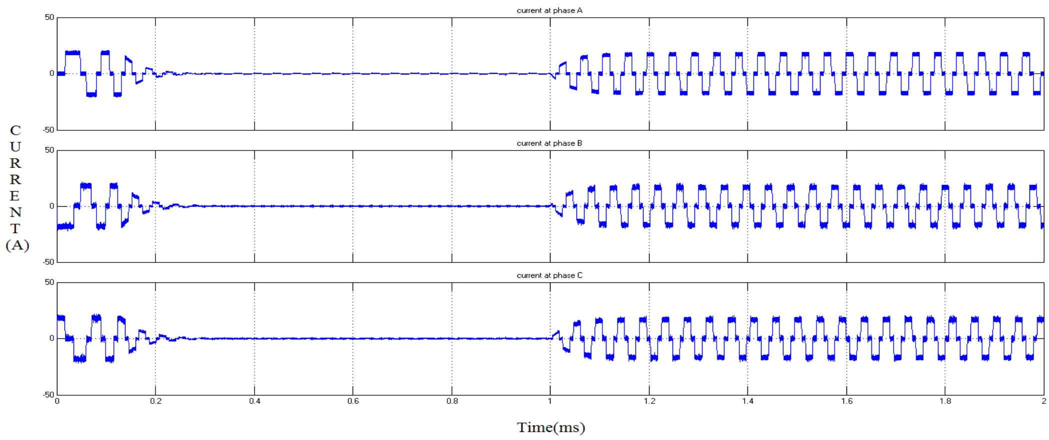

Figure 10: Simulated Waveforms of Input Currents at Reference speed 1500rpm with Load

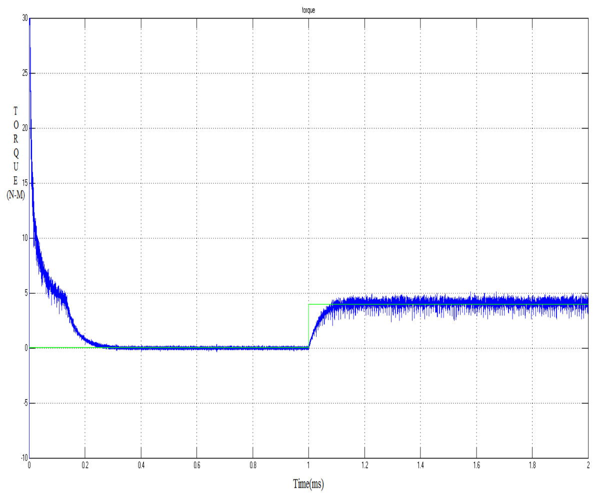

Figure 11: Torque at Reference Speed 1500rpm with Load

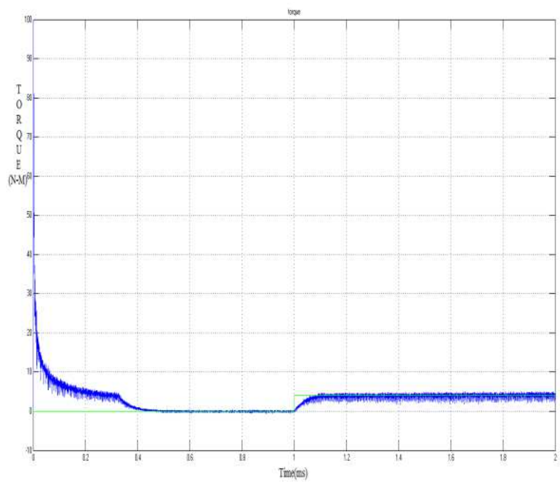

Figure 12: Torque at Reference Speed 3000rpm with Load

Figure 11 and Figure 12 shows the performs of digital PWM controller of BLDC motor at different speeds 1500rpm and 3000rpm the motor Torque at the load at t=0.2 sec

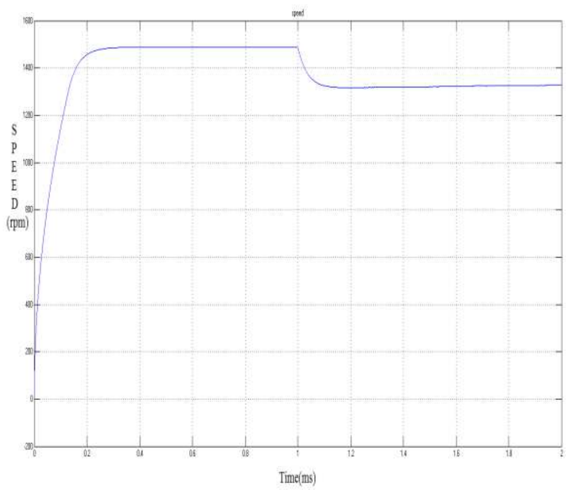

Figure 13: Motor Speed at 1500rpm with Load

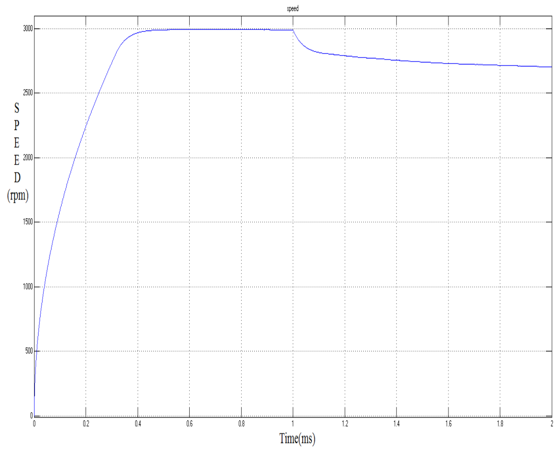

Figure 14: Motor Speed at 3000rpm with Load

Figure 13 and Figure 14 shows the performance of the both the controllers in BLDC Motor speed waveforms are same but the settling time are 1500rpm at t=0.2sec and 3000rpm at t=04sec at the load of 2N-M

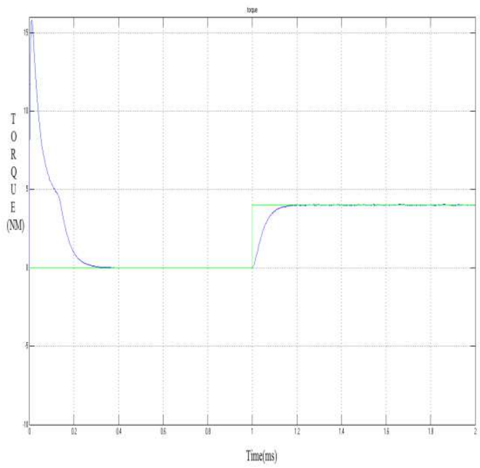

Figure 15: Torque at Reference Speed of 1500rpm with Load

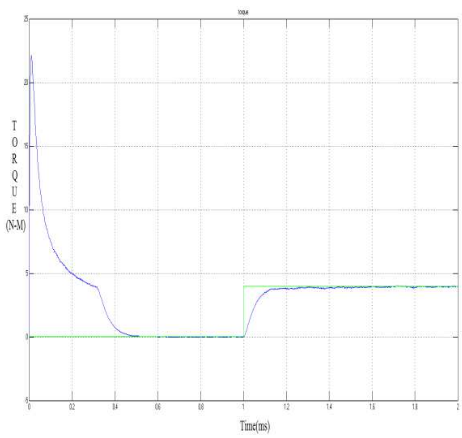

Figure 16: Torque at Reference Speed of 3000rpm with Load

Figure 15 and Figure 16 shows the performs of the new digital controller of BLDC motor, in this controller the torque ripples are reduced for both the speeds.

Hence, this control technique is well suited for applications driven by the conventional scheme with reduced cost and simplicity. Some of the applications where this control technique can be implemented are washing machines, dryers, machine tools, pumps, refrigerators, etc.

CONCLUSIONS

This paper proposed a simple but an effective digital control for BLDC motor drive. Compared with the conventional scheme, this is simple to implement. Simulation has been done with BLDCM to study the proposed motor drive system the digital pulse width modulation (PWM) control technique for trapezoidal brushless DC (BLDC) motor drives. The new controller is adopted to reduce the torque ripple. The results agreed with the theoretical analyses presented in this paper. Therefore, it is expected that the digital control for BLDC motor drives will help reduce the cost and complexity of the motor control hardware; this, in turn, can boost the acceptance level of BLDC motors for commercial mass production applications.

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